Section 2

Earthquakes and Seismic Waves

Reading Preview

Key Concepts

- How does the energy of an earthquake travel through Earth?
- What are the scales used to measure the strength of an earthquake?
- How do scientists locate the epicenter of an earthquake?

Key Terms

- earthquake
- focus
- epicenter
- P wave
- S wave
- surface wave
- Mercalli scale
- magnitude
- Richter scale
- seismograph
- moment magnitude scale

Target Reading Skill

Identifying Main Ideas As you read Types of Seismic Waves, write the main idea in a graphic organizer like the one below. Then write three supporting details. The supporting details further explain the main idea.

Main Idea

Seismic waves carry the energy of an earthquake.

Detail | Detail | Detail

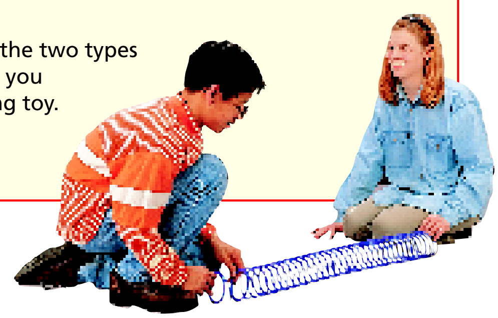
Lab zone Discover Activity

How Do Seismic Waves Travel Through Earth?

1. Stretch a spring toy across the floor while a classmate holds the other end. Do not overstretch the toy.
2. Gather together about four coils of the spring toy and release them. In what direction do the coils move?
3. Once the spring toy has stopped moving, jerk one end of the toy from side to side once. Be certain your classmate has a secure grip on the other end. In what direction do the coils move?

Think It Over

Observing Describe the two types of wave motion that you observed in the spring toy.



Earth is never still. Every day, worldwide, there are several thousand earthquakes. An **earthquake** is the shaking and trembling that results from the movement of rock beneath Earth's surface. Most earthquakes are too small to notice. But a large earthquake can produce dramatic changes in Earth's surface and cause great damage.

The forces of plate movement cause earthquakes. Plate movements produce stress in Earth's crust, adding energy to rock and forming faults. Stress increases along a fault until the rock breaks. An earthquake begins. In seconds, the earthquake releases an enormous amount of stored energy.

Most earthquakes begin in the lithosphere within about 100 kilometers of Earth's surface. The **focus** (FOH kus) is the area beneath Earth's surface where rock that is under stress breaks, triggering an earthquake. The point on the surface directly above the focus is called the **epicenter** (EP uh sen tur).

Section 2

Earthquakes and Seismic Waves

Objectives

After this lesson, students will be able to

F.2.2.1 describe how the energy of an earthquake travels through Earth

F.2.2.2 identify the scales used to measure the strength of an earthquake

F.2.2.3 explain how scientists locate the epicenter of an earthquake

Target Reading Skill

Identifying Main Ideas Explain that it is easier to understand something if you can identify the main idea as well as the details that support this idea.

Answers

Possible answers:

Detail: P waves compress and expand the ground.

Detail: S waves vibrate from side to side as well as up and down.

Detail: Surface waves produce the most severe ground movements.

All in One Teaching Resources

- Transparency F16

Preteach

Build Background Knowledge

L2

Experience with Waves

Ask: **What kinds of waves have you observed?** *(Students probably will mention ocean waves and waves in a lake, a pond, a swimming pool, or even a bathtub.)* **How do waves move in water?** *(They probably will say that the waves move outward from a "push" on the water.)*

Lab zone Discover Activity

Skills Focus observing L1

Materials spring toy

Time 10 minutes

Tips Advise students to hold both ends of the spring securely as they make the waves. If they have difficulty observing differences in the two wave types, allow them to repeat each step several times.

Expected Outcome In Step 2, the coils will move forward and backward along the spring in a straight line. In Step 3, the coils will move from side to side.

Think It Over In Step 2, the coils move forward and back as a wave moves from the compressed end of the spring to the other end in a straight line. In Step 3, the coils move from side to side as a wave moves in a bulge from the jerked end of the spring to the other end.

Instruct

Types of Seismic Waves

Teach Key Concepts L1

Movements of Waves

Focus Set up a row of dominoes, and touch one at one end so that each domino strikes its neighbor and all of the dominoes fall. Explain that energy was transferred first from your hand to the first domino, then to the second domino, and so on. This action is similar to the way that waves carry the energy that is released when rocks move.

Teach Remind students of their experience of creating waves with the spring toy in the Discover activity. Ask: **When the wave moved straight ahead along the spring, which type of earthquake wave did it model?** (*A P wave*) **When the spring moved from side to side, which type of wave did it model?** (*An S wave*) **When you used the spring, where was the focus of the model earthquake?** (*At the end that was compressed and jerked*)

Apply Ask: **Why do surface waves produce more severe ground movements than P waves and S waves do?** (*Because the surface consists of loose soil, sand, gravel, mud, small rocks, and similar materials, rather than solid rock, it is susceptible to greater movement as the particles shift and slide.*)

Extend The Active Art will show students how seismic waves behave and the damage they cause. **learning modality: logical/ mathematical**

All in One Teaching Resources

- Transparency F17

Independent Practice L2

All in One Teaching Resources

- Guided Reading and Study Worksheet: *Earthquakes and Seismic Waves*

Student Edition on Audio CD

Types of Seismic Waves

Like a pebble thrown into a pond, an earthquake produces vibrations called waves. These waves carry energy as they travel outward. During an earthquake, seismic waves race out from the focus in all directions. Seismic waves are vibrations that travel through Earth carrying the energy released during an earthquake. The seismic waves move like ripples in a pond. **Seismic waves carry energy from an earthquake away from the focus, through Earth's interior, and across the surface.** That's what happened in 2002, when a powerful earthquake ruptured the Denali fault in Alaska, shown in Figure 7.

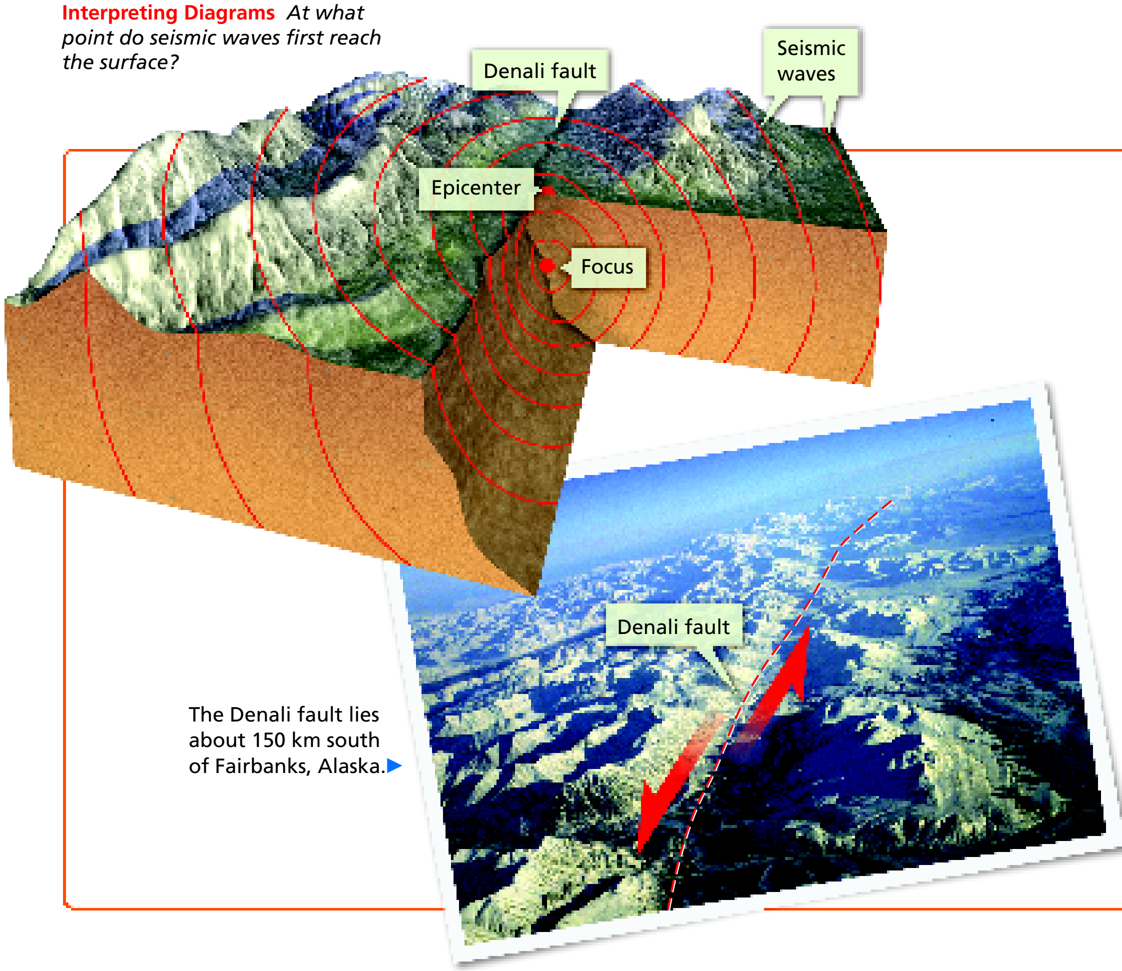
There are three main categories of seismic waves: P waves, S waves, and surface waves. An earthquake sends out two types of waves from its focus: P waves and S waves. When these waves reach Earth's surface at the epicenter, surface waves develop.

FIGURE 7

Seismic Waves

This diagram shows an earthquake along the Denali fault. An earthquake occurs when rocks fracture deep in the crust. The seismic waves move out in all directions from the focus.

Interpreting Diagrams *At what point do seismic waves first reach the surface?*



The Denali fault lies about 150 km south of Fairbanks, Alaska.

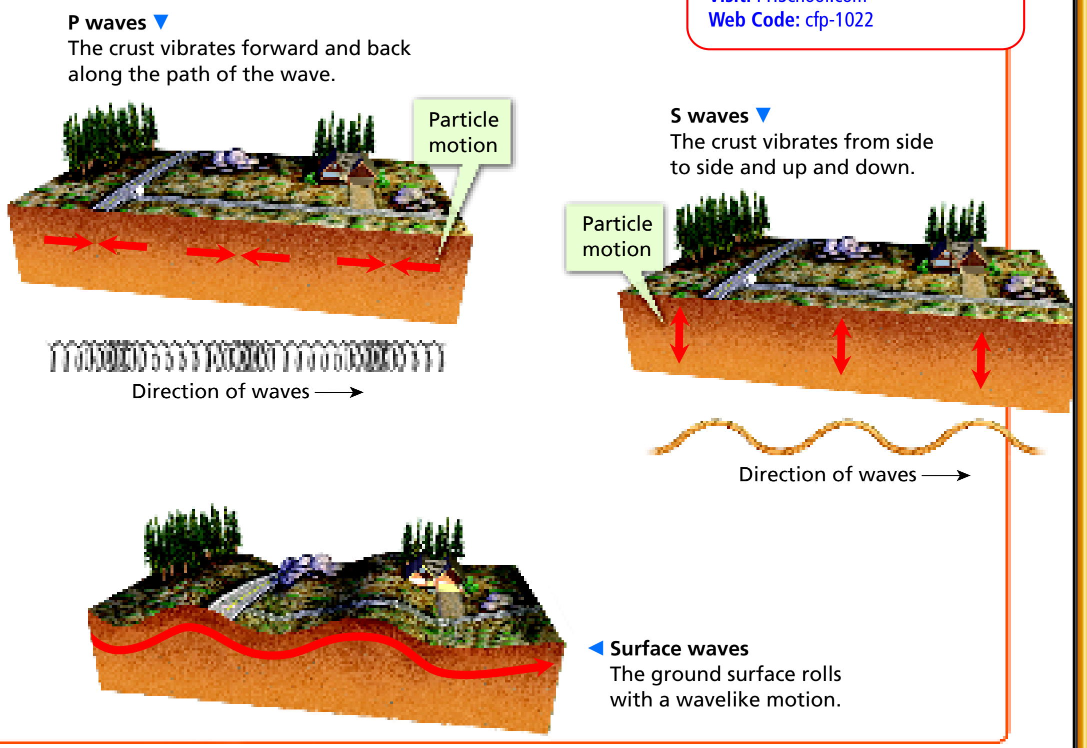
P Waves The first waves to arrive are primary waves, or P waves. **P waves** are seismic waves that compress and expand the ground like an accordion. Like the other types of seismic waves, P waves can damage buildings. Look at Figure 7 to see how P waves move.

S Waves After P waves come secondary waves, or S waves. **S waves** are seismic waves that vibrate from side to side as well as up and down. They shake the ground back and forth. When S waves reach the surface, they shake structures violently. Unlike P waves, which travel through both solids and liquids, S waves cannot move through liquids.

Surface Waves When P waves and S waves reach the surface, some of them become surface waves. **Surface waves** move more slowly than P waves and S waves, but they can produce severe ground movements. Some surface waves make the ground roll like ocean waves. Other surface waves shake buildings from side to side.

Reading Checkpoint **Which type of seismic wave causes the ground to roll like ocean waves?**

Go Online active art
For: Seismic Waves activity
Visit: PHSchool.com
Web Code: cfp-1022



Go Online active art
For: Seismic waves
Visit: PHSchool.com
Web Code: cfp-1022
Students can interact with earthquake seismic waves and watch them move through the crust.

Lab zone Teacher Demo

Comparing Types of Waves L2

Materials dishpans or other wide, shallow containers; water; pebbles

Time 10 minutes

Focus Ask students to recall how waves move when an earthquake occurs. *(They travel outward in all directions.)*

Teach Drop a pebble or another small object into a container filled from six to eight centimeters deep with water. Ask: **How did the waves move when a pebble hit the water?** *(The waves moved outward from the pebble in concentric rings.)* Draw students' attention to the pattern of seismic waves shown in the diagram. Ask: **How are seismic waves like the wave I made when I dropped a pebble into water?** *(Seismic waves also move outward in concentric rings.)* **How are they different?** *(Seismic waves move outward three-dimensionally in all directions, whereas the water waves moved only on the surface. Seismic waves move through solid materials.)*

Apply Using a paper clip, demonstrate P and S waves in the container of water. Have students identify which wave is occurring. Make sure that students understand the two types of waves and that they can accurately identify the differences in the movements they create. **learning modality: visual**

Differentiated Instruction

Less Proficient Readers L1

Identifying Root Words and Suffixes Students may wonder about the origins of the terms *seismic, seismograph, seismologist,* and *seismology*. Encourage students to look up these terms to find their common root. (*From* seismos, *the Greek word for earthquake, derived from* seiein, *meaning "to shake"*) Also discuss the meanings of the suffixes *-graph* (*a device that writes or records*), *-ology* (*"the study of" something*), and *-ologist* (*"a person who studies" something*). **learning modality: verbal**

Monitor Progress L2

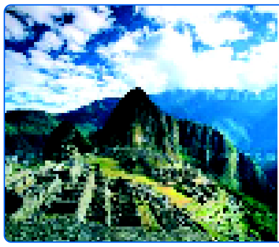
Drawing Have each student draw and label a sketch showing an earthquake's focus underground, its epicenter on the surface, the different motions of P waves and S waves moving outward from the focus, and surface waves moving outward from the epicenter.

Answers

Figure 7 The epicenter

Reading Checkpoint Surface waves

Measuring Earthquakes



Discovery Channel School Video Field Trip

Earthquakes

Show the Video Field Trip to let students experience earthquakes and understand the different ways earthquakes are measured. Discussion questions: **How do the different seismic waves travel?** *(The primary, or P, waves travel fast through the ground and arrive first. The secondary, or S, waves arrive next with side-to-side and up-and-down motions.)* **What kind of ground movement does each one cause?** *(P: initial jolt; S: swaying ground)*

Teach Key Concepts L1

Scales to Measure Earthquakes

Focus Most students probably have heard of the Richter scale. Ask them to share what they know. *(Students may say that the higher the number, the more destructive the earthquake.)*

Teach Ask: **How are the Mercalli scale and the Richter scale similar?** (*Both describe the "strength" of an earthquake.*) **How are they different?** (*The Mercalli scale describes an earthquake's strength in terms of its effects—to what extent people notice it and the amount of damage it causes. The Richter scale describes an earthquake's strength in terms of the size of its seismic waves.*)

Apply Ask: **On which scale would an earthquake's strength vary from one place to another, and why?** (*The Mercalli scale; the amount of shaking that people would feel and the damage to objects would be greater in a place closer to the quake's epicenter and less in a place farther away, so the intensity ratings in the two places would be different.*) **learning modality: logical/mathematical**

Help Students Read L1

Comparing and Contrasting Have students compare and contrast the methods of measuring earthquakes. Ask: **What are we asking when we say, "How big was the earthquake?"** (*Answers should include amount of damage, strength, and energy.*) **learning modality: logical/mathematical**

Discovery Channel School

Earthquakes
- Video Preview
- ▶ Video Field Trip
- Video Assessment

Measuring Earthquakes

When an earthquake occurs, people want to know "How big was the quake?" and "Where was it centered?" When geologists want to know the size of an earthquake, they must consider many factors. As a result, there are at least 20 different measures for rating earthquakes, each with its strengths and shortcomings. **Three commonly used methods of measuring earthquakes are the Mercalli scale, the Richter scale, and the moment magnitude scale.**

The Mercalli Scale The **Mercalli scale** was developed to rate earthquakes according to the level of damage at a given place. The 12 steps of the Mercalli scale, shown in Figure 9, describe an earthquake's effects. The same earthquake can have different Mercalli ratings because it causes different amounts of ground motion at different locations.

The Richter Scale An earthquake's **magnitude** is a number that geologists assign to an earthquake based on the earthquake's size. Geologists determine magnitude by measuring the seismic waves and fault movement that occur during an earthquake. The **Richter scale** is a rating of an earthquake's magnitude based on the size of the earthquake's seismic waves. The seismic waves are measured by a **seismograph.** A seismograph is an instrument that records and measures seismic waves. The Richter scale provides accurate measurements for small, nearby earthquakes. But it does not work well for large or distant earthquakes.

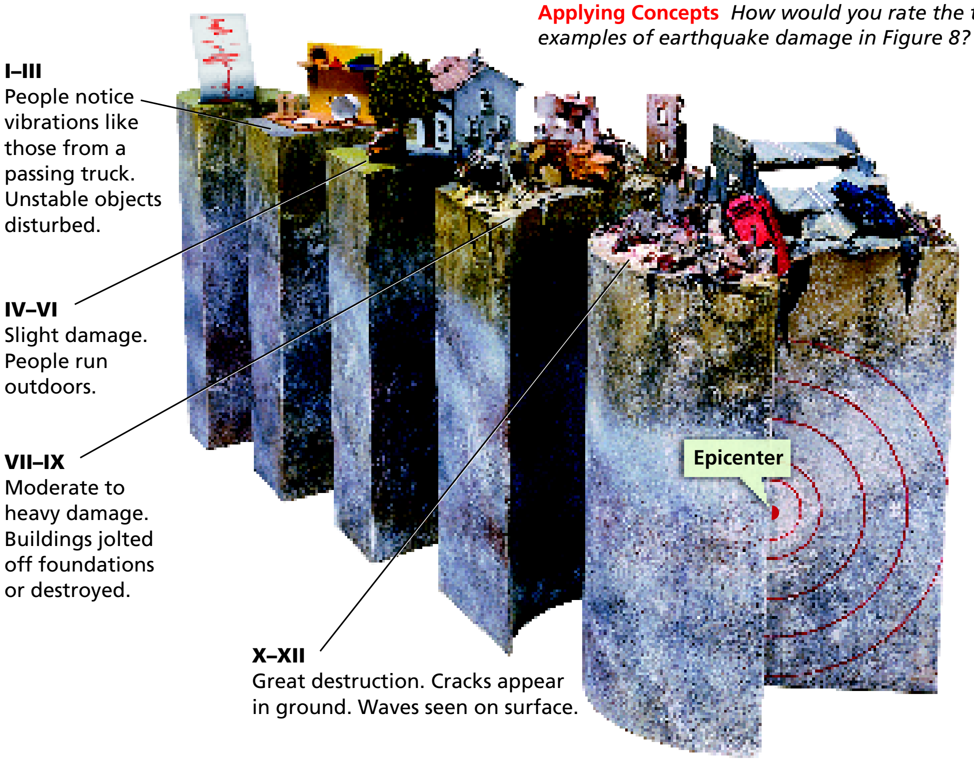
FIGURE 8
Levels of Earthquake Damage
The level of damage caused by an earthquake varies depending on the magnitude of the earthquake and the distance from the epicenter.

Differentiated Instruction

Gifted and Talented L3

Making a Time Line Have students investigate the ten largest earthquakes ever recorded around the world. They can make a banner for each that shows the location, magnitude, and a brief description of the damage. Have students find out whether scientists know what caused each earthquake; for example, experts may know that a large fault lay beneath the area. **learning modality: visual**

FIGURE 9
The Mercalli Scale
The Mercalli scale uses Roman numerals to rank earthquakes by how much damage they cause.
Applying Concepts *How would you rate the three examples of earthquake damage in Figure 8?*



The Moment Magnitude Scale Geologists today often use the **moment magnitude scale,** a rating system that estimates the total energy released by an earthquake. The moment magnitude scale can be used to rate earthquakes of all sizes, near or far. You may hear news reports that mention the Richter scale. But the number they quote is almost always the moment magnitude for that earthquake.

To rate an earthquake on the moment magnitude scale, geologists first study data from seismographs. The data show what kinds of seismic waves the earthquake produced and how strong they were. The data also help geologists infer how much movement occurred along the fault and the strength of the rocks that broke when the fault slipped. Geologists use all this information to rate the quake on the moment magnitude scale.

Reading Checkpoint **What evidence do geologists use to rate an earthquake on the moment magnitude scale?**

Lab zone **Skills Activity**

Classifying

Classify the earthquake damage at these locations using the Mercalli scale.

1. Many buildings are destroyed; cracks form in the ground.
2. Several old brick buildings and a bridge collapse.
3. Canned goods fall off shelves; walls crack; people go outside to see what's happening.

Lab zone **Build Inquiry** L2

Inferring How to Locate the Epicenter

Materials None

Time 15 minutes

Focus Do the following activity in a large area such as a gym. Choose two students to role-play a P wave and an S wave. Position both students at a starting point, and position a third student some distance away to represent a seismograph.

Teach When you say "Earthquake!" have the two students start walking toward the third student, with the "P wave" student taking long forward strides and the "S wave" student taking shorter steps in a waddling gait to represent the side-to-side vibration of S waves. After a few seconds, say "Stop." Then ask: **Which wave is closer to the seismograph?** (*The P wave*) Repeat the activity with six students role-playing three pairs of P and S waves. Assign a number to each pair, and have all three pairs start walking at your signal. Say "One, stop," "Two, stop," and "Three, stop" at intervals. Have the students who are observing compare the distances between the P-wave and S-wave students in the three pairs. Ask: **Are all three distances the same?** (*No*) **How do they vary?** (*The P and S students who were walking for the shortest time are the closest together. The P and S students who were walking for the longest time are the farthest apart.*)

Apply Ask: **How would this difference help a geologist tell how far away an earthquake's epicenter is?** (*If the S waves arrive at a seismograph a very short time after the P waves, the epicenter is close to the seismograph; the longer the interval between the arrival times of the P waves and those of S waves, the farther away the epicenter is.*) **learning modality: kinesthetic**

Lab zone **Skills Activity**

Skills Focus classifying L2

Materials none

Time 5 minutes

Tips Have students refer to Figure 9 to help them answer questions.

Expected Outcome 1. X–XII great destruction; 2. VII–IX moderate to heavy damage; 3. IV–VI slight damage

Extend Have students look at pictures from recent earthquakes and rate the damage, using the Mercalli scale in Figure 9. **learning modality: visual**

Monitor Progress L2

Skills Check Have students compare and contrast the three types of seismic waves.

Answers

Figure 9 Top photo: I–III; middle photos: IV–VI, VII–IX; bottom photo: X–XII

Reading Checkpoint The moment magnitude scale estimates the total energy released by an earthquake by recording the kinds of seismic waves produced and their strength.

Locating the Epicenter

Teach Key Concepts

L1

Mapping an Earthquake's Location

Focus Ask students whether they have listened for thunder after seeing lightning. Ask: **Why do you hear thunder after you see lightning?** *(The sound waves of thunder travel more slowly than the light waves of lightning.)* Remind students that the time it takes for thunder to be heard after lightning flashes is an indication of how far away the lightning is. The same principle is used to find the location of an earthquake's epicenter.

Teach Review the meaning of the word *radius* (the distance from the center of a circle to its circumference), and have students find radii on the map in Figure 11. Ask: **Why have three circles been drawn on this map?** (*Each of the three circles was drawn on the basis of data from a different seismograph. The center of each circle is the location of one seismograph. The point at which the three circles intersect marks the epicenter of the earthquake.*)

Apply Ask: **Why would two circles not be enough to determine the epicenter?** (*Two circles would intersect at two points, not one, identifying two possible epicenters.*) **learning modality: visual**

Math Analyzing Data

Math Skill Making and Interpreting Graphs

Focus Point out the line graph, and discuss why this is an appropriate representation of the data.

Teach Review with students what the axes mean and how the grid is structured. Ask: **What is on the vertical axis?** *(Arrival time in minutes)* **What is on the horizontal axis?** *(Distance from epicenter in kilometers)* **What do the points on the graph show?** *(Plotted data)*

Answers

1. *x*-axis: distance from the epicenter; *y*-axis: arrival time
2. 4 minutes
3. 7.5 minutes
4. 2,000 = 3.5 minutes
4,000 = 4.5 minutes

FIGURE 10
Collecting Seismic Data
This geologist is checking data collected after an earthquake. These data can be used to pinpoint the epicenter of an earthquake.

Comparing Magnitudes An earthquake's magnitude tells geologists how much energy was released by the earthquake. Each one-point increase in magnitude represents the release of roughly 32 times more energy. For example, a magnitude 6 quake releases 32 times as much energy as a magnitude 5 quake, and about 1,000 times as much as a magnitude 4 quake.

The effects of an earthquake increase with magnitude. People scarcely notice earthquakes with magnitudes below 3. Earthquakes with a magnitude below 5 are small and cause little damage. Those with a magnitude between 5 and 6 can cause moderate damage. Earthquakes with a magnitude above 6 can cause great damage. Fortunately, the most powerful earthquakes, with a magnitude of 8 or above, are rare. During the twentieth century, only two earthquakes measured above 9 on the moment magnitude scale. These earthquakes occurred in Chile in 1960 and in Alaska in 1964.

Locating the Epicenter

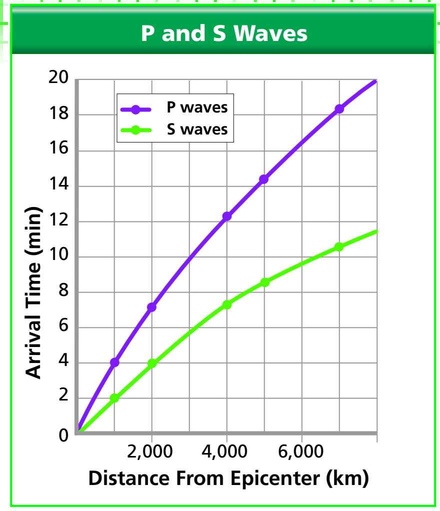
Geologists use seismic waves to locate an earthquake's epicenter. Seismic waves travel at different speeds. P waves arrive at a seismograph first, with S waves following close behind. To tell how far the epicenter is from the seismograph, scientists measure the difference between the arrival times of the P waves and S waves. The farther away an earthquake is, the greater the time between the arrival of the P waves and the S waves.

Math Analyzing Data

Seismic Wave Speeds

Seismographs at five observation stations recorded the arrival times of the P and S waves produced by an earthquake. These data are shown in the graph.

1. **Reading Graphs** What variable is shown on the *x*-axis of the graph? The *y*-axis?
2. **Reading Graphs** How long did it take the S waves to travel 2,000 km?
3. **Estimating** How long did it take the P waves to travel 2,000 km?
4. **Calculating** What is the difference in the arrival times of the P waves and the S waves at 2,000 km? At 4,000 km?



Locating an Epicenter

FIGURE 11
The map shows how to find the epicenter of an earthquake using data from three seismographic stations. **Measuring** *Use the map scale to determine the distances from Savannah and Houston to the epicenter. Which is closer?*

Geologists then draw at least three circles using data from different seismographs set up at stations all over the world. The center of each circle is a particular seismograph's location. The radius of each circle is the distance from that seismograph to the epicenter. As you can see in Figure 11, the point where the three circles intersect is the location of the epicenter.

Reading Checkpoint **What do geologists measure to determine the distance from a seismograph to an epicenter?**

Section 2 Assessment

Target Reading Skill

Identifying Main Ideas Use your graphic organizer to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Reviewing** How does energy from an earthquake reach Earth's surface?
   b. **Describing** What kind of movement is produced by each of the three types of seismic waves?
   c. **Sequencing** When do P waves arrive at the surface in relation to S waves and surface waves?
2. a. **Defining** What is an earthquake's magnitude?
   b. **Describing** How is magnitude measured using the Richter scale?
   c. **Applying Concepts** What are the advantages of using the moment magnitude scale to measure an earthquake?
3. a. **Explaining** What type of data do geologists use to locate an earthquake's epicenter?
   b. **Interpreting Maps** Study the map in Figure 11 above. Then describe the method that scientists use to determine the epicenter of an earthquake.

Writing in Science

News Report As a television news reporter, you are covering an earthquake rated between IV and V on the Mercalli scale. Write a short news story describing the earthquake's effects. Your lead paragraph should tell *who, what, where, when,* and *how*. (*Hint:* Refer to Figure 9 for examples of earthquake damage.)

Lab zone Chapter Project

Keep Students on Track Encourage volunteers to describe any changes they made in their initial designs. Have students review their agreed-upon criteria for simulating earthquakes so that all models are subjected to the same degree of shaking. Emphasize the importance of taking notes about any damage that the models sustain and any weaknesses that are revealed.

Writing in Science

Writing Skill Cause-and-effect

Scoring Rubric
4 includes descriptions of earthquake effects and the who, what, where, when, and how of a news account; reads like an actual news account
3 includes all criteria
2 includes one or two of the criteria
1 includes inaccurate details

Monitor Progress L2

Answers
Figure 11 Houston (about 800 km compared with about 900 km for Savannah)

Reading Checkpoint The difference between the arrival times of the P waves and S waves

Assess

Reviewing Key Concepts

1. a. Seismic waves carry the energy of an earthquake away from the focus. Some of those waves reach the surface and become surface waves. **b.** *P waves:* Compress and expand the ground as they travel; move through solids and liquids; are the fastest-moving seismic waves. *S waves:* Vibrate from side to side and up and down as they travel; move only through solids. *Surface waves:* Move along the surface; move more slowly than P and S waves; can produce violent ground movements. **c.** P waves are the first waves to arrive during an earthquake, followed by S waves. As P and S waves reach the surface, they are transformed into surface waves.
2. a. A measurement of earthquake strength based on seismic waves and movement along faults **b.** The Richter scale describes an earthquake's strength in terms of the size of its seismic waves. **c.** It can rate all sizes of earthquakes, near or far.
3. a. Seismic waves **b.** Geologists measure the difference between arrival times of the P and S waves, using data from three seismographs. They then draw three circles, using the data from the seismographs. The point at which the circles intersect is the location of the epicenter.

Reteach L1

Ask students to illustrate how primary, secondary, and surface waves travel, and how seismologists use the waves' characteristics to determine the distance to an earthquake epicenter.

All in One Teaching Resources
- Section Summary: *Earthquakes and Seismic Waves*
- Review and Reinforcement: *Earthquakes and Seismic Waves*
- Enrich: *Earthquakes and Seismic Waves*

Lab zone Skills Lab

Finding the Epicenter L3

Prepare for Inquiry

Key Concept

Data from seismographs in three different locations can be used to identify an earthquake's epicenter.

Skills Objectives

Students will be able to

- interpret data to determine the distances of three seismographs from an earthquake's epicenter
- draw a conclusion about the location of the earthquake's epicenter

Prep Time 5 minutes

Class Time 35–40 minutes

Advance Planning

Make a photocopy of the map for each student.

Guide Inquiry

Invitation

Ask: **Why is it important for scientists to know where an earthquake's epicenter is located?** (*Accept all reasonable responses, such as the usefulness of this information in predicting future earthquakes.*) Then have students refer to Figure 11 on the previous page. Explain that in this activity, they will use the same technique to find an earthquake's epicenter.

Introducing the Procedure

Before students begin, review the use of a drawing compass and a map scale. Ask: **What do the numbers on the compass represent?** (*The distance in centimeters between the compass's metal point and the pencil point*) **If you set the compass at 7 and drew a circle, what would the circle's diameter be?** (*14 cm*) **What would its radius be?** (*7 cm*)
Next, ask: **What does a map scale show?** (*The distance on the map that represents a certain number of kilometers or miles on the real land surface*) **What is this map's scale?** (*Each centimeter on the map represents 300 km on land. If students cannot answer your question, have them lay a metric ruler along the scale line to see how many kilometers are represented by each centimeter.*) **Suppose that you wanted to show a distance of 1800 km away from Denver on this map. How would you determine the length of that map measurement in centimeters?** (*Divide the distance you want to show by the number of kilometers represented by 1 cm on the map: 1800 km ÷ 300 km = 6 cm on the map.*)
Then ask: **How would you use the compass to measure that distance?** (*Set the compass arm at 6 cm, hold the metal point on the dot for Denver, and draw a circle. To determine the compass setting, students also could hold the metal point on the 0 end of the scale line and adjust the compass arm so that the pencil point is at 1800 km on the line.*) **What does the circle show?** (*All the points 1800 km away from Denver*) If students need more practice, give them additional examples, not including the distances they will use in the activity.

Lab zone Skills Lab

Finding the Epicenter

Problem

How can you locate an earthquake's epicenter?

Skills Focus

interpreting data, drawing conclusions

Materials

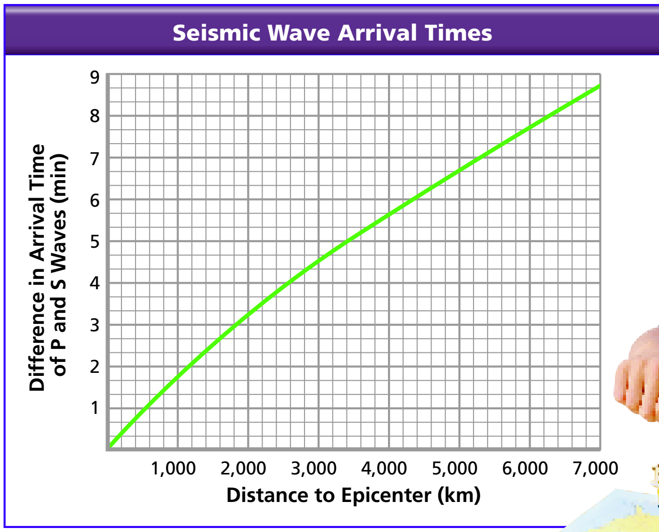
- drawing compass with pencil
- outline map of the United States

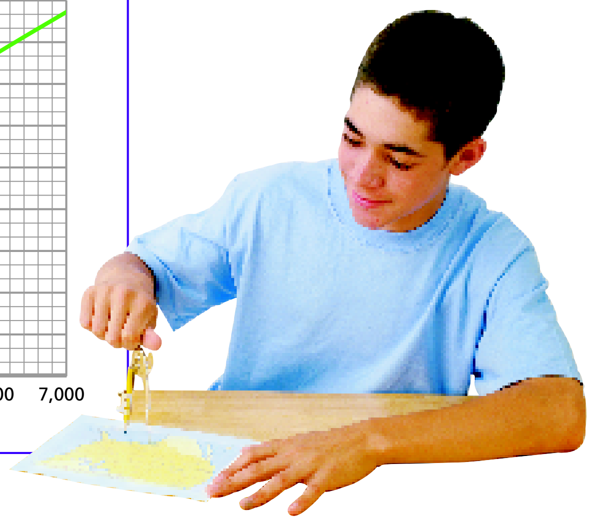
Data Table

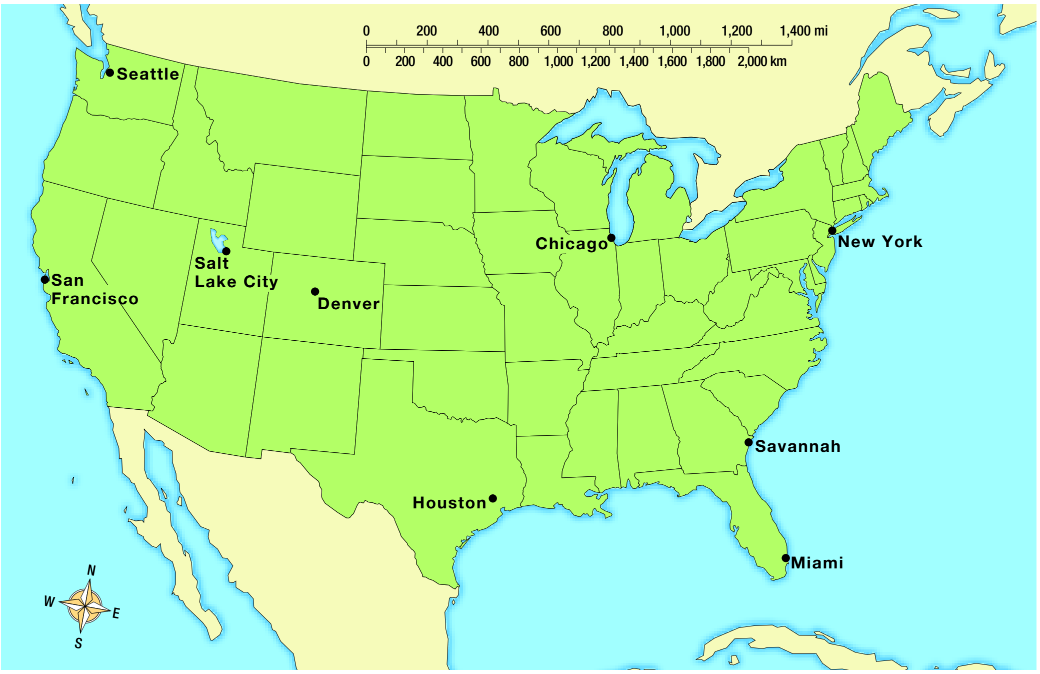
City	Difference in P and S Wave Arrival Times	Distance to Epicenter
Denver, Colorado	2 min 40 s	
Houston, Texas	1 min 50 s	
Chicago, Illinois	1 min 10 s	

Procedure

1. Make a copy of the data table showing differences in earthquake arrival times.
2. The graph shows how the difference in arrival time between P waves and S waves depends on the distance from the epicenter of the earthquake. Find the difference in arrival time for Denver on the *y*-axis of the graph. Follow this line across to the point at which it crosses the curve. To find the distance to the epicenter, read down from this point to the *x*-axis of the graph. Enter this distance in the data table.
3. Repeat Step 2 for Houston and Chicago.
4. Set your compass at a radius equal to the distance from Denver to the earthquake epicenter that you previously recorded in your data table.
5. Draw a circle with the radius determined in Step 4, using Denver as the center. Draw the circle on your copy of the map. (*Hint:* Draw your circles carefully. You may need to draw some parts of the circles off the map.)
6. Repeat Steps 4 and 5 for Houston and Chicago.







Analyze and Conclude

1. **Drawing Conclusions** Observe the three circles you have drawn. Where is the earthquake's epicenter?
2. **Measuring** Which city on the map is closest to the earthquake epicenter? How far, in kilometers, is this city from the epicenter?
3. **Inferring** In which of the three cities listed in the data table would seismographs detect the earthquake first? Last?
4. **Estimating** About how far from San Francisco is the epicenter that you found? What would be the difference in arrival times of the P waves and S waves for a recording station in San Francisco?
5. **Interpreting Data** What happens to the difference in arrival times between P waves and S waves as the distance from the earthquake increases?
6. **Communicating** Review the procedure you followed in this lab and then answer the following question. When you are trying to locate an epicenter, why is it necessary to know the distance from the epicenter for at least three recording stations?

More to Explore

You have just located an earthquake's epicenter. Find this earthquake's location on the map of Earthquake Risk in the United States. What is the risk of earthquakes in the area of this quake?

Now look at the map of Earth's Lithospheric Plates. What conclusions can you draw from this map about the cause of earthquakes in this area?

Troubleshooting the Experiment

- In Step 2, point out that the arrival-time differences listed in the table include seconds as well as minutes, whereas the labels on the *y*-axis give only whole minutes. Therefore, students will need to use the lighter lines on the graph to estimate the partial-minute differences as closely as they can. (Because there are two lighter lines dividing each whole-minute interval into three parts, each lighter line represents 20 seconds.)
- Remind students that they must use the map scale to determine where to set the compass arm for each distance in Steps 4 and 6.

Expected Outcome

The correct compass settings are 5.2 centimeters for Denver, 3.4 centimeters for Houston, and 2 centimeters for Chicago. The point on the map at which all three circles intersect will be about 600 kilometers south of Chicago.

Analyze and Conclude

1. The epicenter is located east of the Mississippi River on the border of Kentucky and Tennessee.

2. Chicago; 600 kilometers

3. *First:* Denver; *Last:* Miami

4. 2,900 kilometers from San Francisco; 4 minutes 25 seconds

5. The difference in arrival times also increases.

6. Using three recording stations enables you to identify one actual epicenter location, whereas using only two stations identifies two possible epicenter locations.

Extend Inquiry

More to Explore This earthquake was not a freak event because it occurred in an area of moderate risk. Earthquakes in this area are caused by movement along the boundary between the Pacific and North American plates.

All in One Teaching Resources

Lab Worksheet: *Finding the Epicenter*